Reduced Order modeling of high magnetic field magnets

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The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a French large scale facility [**?**] enabling researchers to perform experiments in the highest possible magnetic field (up to 35 T static field provided by water cooled resistive magnets connected with a 24 MW power supply). In the race for higher field, existing magnet technologies are pushed to the limits in terms of material properties and design methods. This is even more true for magnets where either the field profile or the field homogeneity (eg. for NMR applications) is also targeted. The design and optimization of these magnets require from

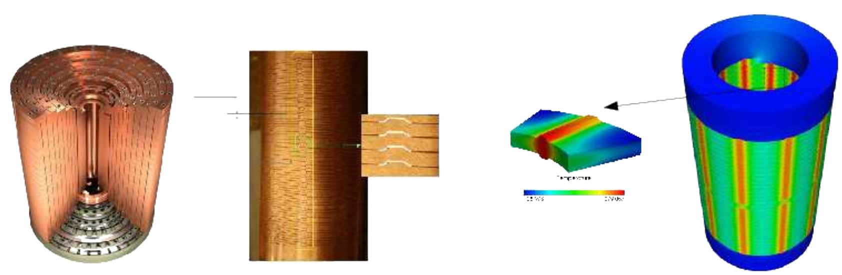

Figure 1. On the left : a view of a 35 tesla magnet; on the right a detailled view of the inner part of the magnet with a zoom on the cooling channels and insulators. Temperature field within this part is displayed on the same figure.

an engineering point of view the prediction of "quantities of interest" or performance metrics, which we shall denote outputs namely magnetic field in the center, maximum stresses, maximum and average temperatures. These outputs are expressed as functionals of field variables associated with a set of coupled parametrized PDEs which describe the physical behavior of our magnets. The parameters, which we shall denote inputs, represent characterization variables such as physical properties, heat transfer coefficients, water temperature and flowrate, and geometric variables in optimisation studies. To evaluate these implicit input/output relationships, solutions of a multi-physics model involving electro-thermal, magnetostatics, electro-thermal-mechanical and thermo-hydraulics are requested. It should be noted that this model is non-linear as the material properties depend on temperature. In practice these evaluations represent a huge computational time but they are mandatory to improve the magnet design as we can no longer rely on common physical sense.

To significantly reduce this computational time, we choose to use model order reduction strategies, and specifically to use the reduced basis method [**?**, **?**, **?**]. This method is well adapted in this context of many model evaluations for parametric studies, inverse problems and uncertainty quantification. We will present the RB method applied to our non-linear coupled models starting with the example of the

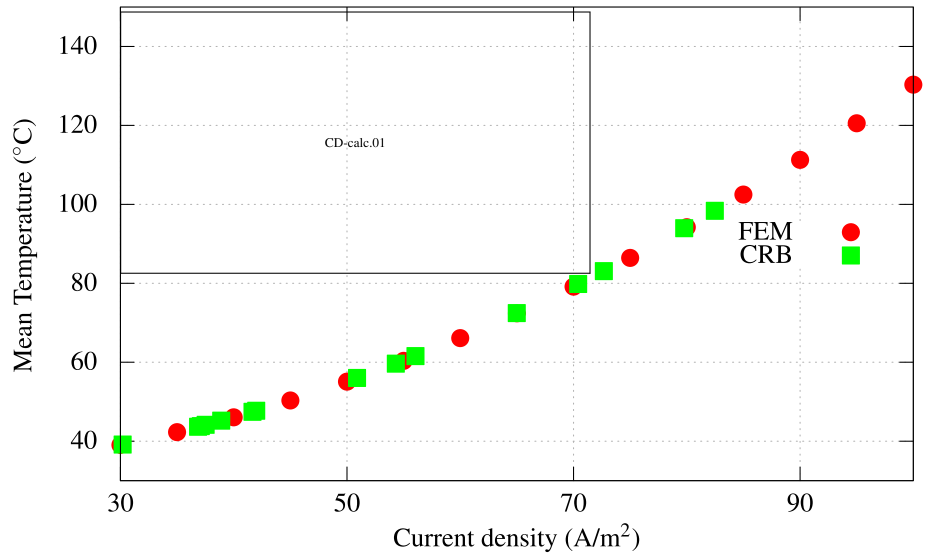

Figure 2. Parametric study of the mean temperature of a Bitter magnet sector.

electro-thermal coupled problem which is the basis of our design. We build upon the feel++ reduced basis framework ([**?**, **?**]) and rely on the openturns (http://www.openturns.org/) library for uncertainty quantifications. Validations and examples will be presented for small to large magnet models. Ungoing developments to include more physics in our models (eg. electro-thermal-mechanical phenomena) will be discussed.

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